

Navigation Network Operational Considerations

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The development of the philosophy necessary for the initial operations costing of the three candidate NAVNET designs is described. The effect of the need to minimize costs upon the operations and maintenance concepts, the simplification of operations by adopting the VLBI principle as a basis for the operating scenarios, and the estimation of the annual load factor based upon an assumed mission set are detailed.

I. Introduction

The need for accurate deep space navigation has been steadily increasing over the years as the objectives of the flight projects have become more demanding. In recognition of the need for a new form of navigation, the Navigation Network (NAVNET) Project was initiated with the objective of providing an operational navigation system by the mid-1980s. The project was divided into four phases, the first two of which were concerned with the definition of the system. The purpose of Phase A was to examine and evaluate the technologies pertinent to navigation in deep space and it was completed in October 1979. The purpose of Phase B was to explore system concepts that might satisfy future DSN navigation requirements. It began in September 1979 and was due to run through September 1980. However, in February 1980, the Phase B completion date was advanced to 1 May 1980 and the purpose diminished to making a study of three given system configurations. This action was taken to enable an effective interface to be made with the Networks Consolidation Project and to hasten the determination of the need to utilize existing STDN facilities for navigational purposes. The new study task

was to develop a preliminary design at the planning level for each of the three given configurations supported by

- (1) implementation costs
- (2) operations and use costs
- (3) an error budget and performance capabilities
- (4) operability characteristics and the impact on other network functions

A description of three given configurations is provided in Table 1. In addition, it was required that the study identify all areas where any further development, analysis, or demonstration activity would be needed to satisfy the design requirements. The work described below is concerned principally with the operations and use costs, the operability characteristics, and the impact on other network functions. The narrative represents the thinking that was done, in the limited time available, to develop operational concerns to the point where costs could be credibly estimated for each one of the preliminary designs.

The Planning Configuration, as its name implies, served as a useful vehicle for the incubation and development of ideas from the inception of the NAVNET Project. It was mandated from the beginning of the Project that the principle of Life Cycle Costing would be applied to any system that may be based ultimately on this configuration (or any other). It was intended that the implemented system would be automated for remote control and therefore would need to be highly reliable in operation. The corollary was that operation and maintenance costs would be thus minimized and this idea became a major design constraint. Although this corollary was considered to be a necessary constraint on Configurations 2 and 3 also, it was not thought to be sufficient. It was felt that because the existing DSN might be modified to accommodate other needs in addition to those of the navigation requirements, then any NAVNET design should be consistent (a) with the 1985-era consolidated network, and (b) in system operations.

II. General Operational and Maintenance Concepts

A. Configuration-1 Stations

There were several possible ways in which the general constraint of minimizing operations and maintenance costs could be realized in the preliminary design of the three terminals (stations). The intuitive but unchallenged choice, however, was to limit the options to the one where the terminal equipment could be operated in the unattended mode; that is, with no operator on duty at any of the three site locations. This implied that the essential operator functions would have to be performed remotely. JPL was chosen as the concentration point for the three terminal controls because it was also the location of both the DSN Operations and Communications Centers. The further implication was that no navigation data recording or buffering activities that required operator assistance could be supported at an unattended terminal. Hence, navigation data acquired at any terminal would have to be formatted and transmitted in real time for processing at a central correlator that could be conveniently colocated with the terminal controls. Also, Block II VLBI recording equipment used for radio source calibration purposes would have to be suitably modified to avoid the need for operator attendance. A possible alternative would be to use on-site maintenance personnel to make the necessary tape changes on those few days each year when that activity would be necessary.

The Goldstone anchor station, being a standard DSN station, would be constrained by existing policies in regard to operations costs. Since the anchor station NAVNET activities would not include the acquisition of telemetry data, the

implication was that no increase in operations manpower would be needed.

From the very beginning of the NAVNET Project, it was felt that a good guideline for such a dedicated network would be "if we don't get the data today then we will try again tomorrow." This idea loomed large in the selection of a system operational availability factor of 0.95 as a basis for the estimation of the equipment failure rate. It was further understood from the system designer that the "best" angle measurement would be obtained if all three of the terminals were to be operating concurrently. To simplify the calculations, the system was considered to be composed of just the three terminals, each one including eight subsystems, all of them operating simultaneously. The correlator and the connecting data links were assumed to be failure free. On this basis, the subsystem availability factor turned out to be 0.998.

Remembering that a basic constraint was to minimize maintenance personnel costs, the maintenance effort was based upon a staff on-site presence limited to an 8.5 hours per day on 5 days per week. The average response time to an equipment failure was then calculated to be 14.9 hours. Also assuming a mean time to repair (MTTR: the mean time to restore a failed subsystem to a serviceable condition once the repair work had begun) of 1 hour, the subsystem's mean time between failures (MTBF) was estimated to be around 7400 hours. The system designer considered that a subsystem failure rate of one per year would be an acceptable design goal for all of the subsystems excepting the hydrogen maser. Experience with hydrogen masers in the field to date had indicated that these frequency standards were not yet truly operational devices. It was considered that product improvement over the next five years would make station operations possible using redundant hydrogen masers to achieve the necessary level of availability.

From an operations viewpoint, the high estimated value of the subsystem MTBF at the remote terminals implied that:

- (1) The corrective maintenance activities to be performed by the local staff would be minimal. Extensive training of the staff in fault location and repair of the complex equipment could not be justified, because the skills acquired would seldom be used and would atrophy through insufficient exercise. Restoral of service following an equipment failure should therefore be supported by the provision of built-in test equipment (BITE) to enable semiskilled personnel to locate and identify the problem to the unit replacement level.
- (2) It would not be cost effective to provide local facilities with test and ancillary equipment to permit local repairs to be made to failed replaceable units. So replaceable unit repair should be performed elsewhere

within the DSN and local repairs should be limited to those areas where removal and replacement would be impractical, e.g., structures, cables, and connectors.

Here one may begin to see the dimensions of a design for testability (Ref. 1) problem, a problem for which there was no time to investigate. The analysis had led to where a field test using BITE should be made to determine which equipment item should have to be replaced to restore system serviceability within an average period of one hour. A bench test would be made at a later time to determine which part(s) would have to be replaced within the specific equipment item, the repair turnaround time of which would have to be specified. The bench test might or might not be performed using Automatic Test Equipment (ATE). It would depend upon the result of the tradeoff that would have to be made between the field- and bench-test approaches to achieve the minimum life-cycle cost for sustaining the system availability. An important practical concern would be to ensure that the functional partitioning of the equipment for testing purposes resulted in replaceable electronic equipment items that could be handled by one person and replaceable mechanical equipment items that could be handled by at most two persons, perhaps aided by simple lifting apparatus.

The implied skill limitations of the maintenance staff and the limited test equipment capabilities on site, further implied that limitations should be imposed upon the scope of equipment modifications to be made at the terminals subsequent to the initial implementation. Minor modifications should not require more than two semiskilled persons to complete the installation and checkout in an 8-hour shift. This would mean that modifications would have to be supplied complete, configured, and ready to connect. Major modifications would have to be installed by a special team with necessary equipment sent for the purpose and supported by the local staff.

A special effort would be required in the antenna design to minimize the effect of failure upon system operability. DSN experience indicated that several years might pass before a failure occurred in the antenna mechanical subsystem. However, the subsequent downtime was of the order of days rather than hours. The implication was that the antenna equipment status monitoring should be more automated and that visual inspection capability should be improved to reduce the risk of operational failure.

The cost of equipment maintenance at the Goldstone anchor station would be minimized by utilizing the services already provided at the Complex. Since the station would continue to be a standard DSN station, modifications should be handled in the same way as for other similar DSN stations.

B. Configurations 2 and 3

In these two configurations, the stations would be either existing or upgraded DSN stations within the Consolidated Network, with features depending upon the particular configuration. This implies that there would continue to be a station operator presence. The availability of a station operator would mean that the modifications to the station equipment to do the new navigation activities would require only evolutionary changes to existing operational procedures in contrast to new procedures for the unattended operations required for Configuration 1.

Operator presence would permit local recording of data and so provide relief from the relative inflexibility of the system operational coordination that would be required in Configuration 1, to provide up to three concurrent extra wide-band (~1-MHz) streams of real-time data from different geographical locations to the NOCC. Furthermore, by playing back the recorded data in nonreal time at a lower rate than that at which it was recorded, the reduced data link bandwidth requirement would reduce communications costs.

The operators would be trained to do station-level troubleshooting and to effect a service restoral by replacing a failed unit. This capability would reduce the average maintenance response time from 14.9 hours for Configuration 1 to zero, which in turn would considerably reduce the subsystem MTBF needed to achieve a particular operational availability factor. The reduced equipment-reliability requirement would result in lowered implementation costs.

The Hawaiian terminal, relegated to the role of being a backup for either Goldstone or Canberra in both Configurations 2 and 3, would no longer be considered a candidate for being remotely controlled on the grounds of both cost of implementation and in consistency of operation. The implication was that the terminal should be designed for local operation in a manner similar to that of the standard DSN locations.

It should be further noted that operator attendance, while reducing the average response time to a failure quite dramatically when compared with Configuration 1, would have no effect upon the availability of a hydrogen maser. Hence, redundant hydrogen masers would be needed at each NAVNET location.

In Configuration 3, the addition of an X-band transmitter at each location would create a new risk factor due to the lack of operational experience with the equipment. This risk translated into a need for a human equipment monitor to be on duty at least during each transmitter startup and shutdown

period, until an appropriate level of confidence as to its operational integrity could be established.

The maintenance philosophy for Configurations 2 and 3 had to be approached somewhat differently to that for Configuration 1. It was not the design intent to develop an entirely new station configuration, but rather to make small but significant modifications to an existing DSN station configuration at the subsystem and assembly levels. This implied that any changes in maintenance philosophy would necessarily be small and evolutionary (Ref. 2). It has already been noted that an operator would be available for first line troubleshooting. However, the station operator would be getting direction by voice from the Operations Chief on those occasions when a failure involved loss of data production at the central correlator.

The philosophy of providing modification kits for NAVNET equipment would clearly have to be consistent with that for supporting existing DSN equipment in the Consolidated Network.

The Hawaiian station in both of these configurations was conceived as being built of existing or projected DSN equipment and its maintenance and operation would be based on those existing or projected policies for current DSN Stations.

C. JPL

1. **NOCC.** From the earliest days of the DSN it was an essential function of the NOCC (or its predecessor) to ensure that the stations had the necessary prior information to make them self-sufficient in conducting specific operations in case communications with JPL were interrupted during the real-time event. The stations were designed to process acquired signals, record the data as a precaution against communication failure, and also transmit that data in real time to JPL where it could be monitored to determine the adequacy of the performance of the single station data acquisition system. The NOCC controller would inform the station operators of any data discrepancy occurrence as observed on a Real-Time Monitor (RTM), and would provide them with system troubleshooting direction to help them discharge the local responsibility for effecting system recovery.

The introduction of the VLBI data type into the DSN for spacecraft navigation would create an important change in the operational philosophy of the NOCC for all three of the configurations to be considered. With VLBI, a multistation data type, a signal would be acquired at two or more geographically separated stations and transmitted over as many different data links to the correlator at JPL. The correlator, a multisignal processor, would produce the observable data.

Hence, the signal processing function would be removed from the stations and relocated at the NOCC. Should observable data fail to be produced when expected, the NOCC personnel would have a more intimate involvement in achieving system recovery for this data type than for any other. NOCC personnel would be responsible for the operation of the data-producing correlator and would therefore be cast as active participants in the total data production process. The NOCC would be an active component in a distributed data production system that could be debugged only by working logically from the observable data generation point towards each signal source. The Operations Chief would have to play a significant role in system troubleshooting. To assist him, it would be necessary to provide voice-communication lines that traversed routes different than the wide-band data links to the stations. This would reduce the probability of concurrent voice and data failure, and so help to improve the system availability. The dimensions of control would include pass continue/abort decisions based upon the presence or absence of correlator "fringe" data, the direction of system level troubleshooting and network rescheduling subsequent to system recovery from a failure. The colocation of the NAVNET operations terminal controls and the NOCC required by Configuration 1 would have implications for further changes in NOCC functional design. The additional control dimensions would include schedule generation, predicts generation, and choice of configuration. It would make a lot of sense to include both the monitor and control functions within the NOCC environmental focus. "Monitor" provides the human stimulus to take action, and "Control" provides the means for implementing a response, so closing a natural loop. The existing DSN hybrid arrangement within the NOCC, whereby system control responses based upon monitor stimuli are exercised for the NOCC Controller vicariously by the station operator could lead to nonoptimal behavioral situations for both of these persons.

2. **GCF.** A clear need has been established in the foregoing narrative for simplex data links and full duplex voice links by a different route, between each of the NAVNET stations and JPL for all the configurations to be considered. It was assumed that although additional equipment would need to be installed within the GCF, no additional staff would be needed to operate it.

III. Station Operational Scenarios

In the process of conceptualizing the operational scenarios, two constraints upon the system characterization had to be considered. The first of these was that the operational calibration of the implemented system had to be accomplished by techniques and equipment being developed under the DSN VLBI System. The second was that all high-accuracy radio

navigation instrumentation had to use X-band as the primary measurement frequency, with S-band for calibration support or low- to medium-accuracy measurement service. The first of these constraints proved to be a highly significant factor in optimizing the operational scenarios, while the latter retained its latency for future performance upgrades.

A number of different fundamental radio metric data types had been described in the NAVNET Phase A Report (Ref. 3). These were studied and the system designer selected two different VLBI data types for making angle and angle-rate measurements in all three of the configurations to be developed and evaluated. The data types chosen were differenced one-way range (DOR) to satisfy medium accuracy angle measurement needs, and quasar-spacecraft differenced VLBI (Δ VLBI) to meet the higher accuracy needs. These choices gave congruity to the operational activities necessary for making both the spacecraft navigation angle measurements and the system calibrations needed to validate them. Expressed from the operator viewpoint, a change in the level of measurement accuracy for a particular spacecraft would not require any change in the operating technique, but could involve a change in the frequency with which the measurement was being made and also a change in the frequency of performing system calibrations. This uniformity of operation would manifest itself in limiting the need for versatility in operating skills and therefore the amount of effort needed to train operators; also in productivity because the uninterrupted familiarity of operation would eliminate the procedural errors induced by changes in task.

Ranging and range-rate data would be obtained in all three configurations in the conventional two-way mode, with X-band being used in Configuration 3. The ranging and VLBI activities, if scheduled concurrently, would place demands on spacecraft transmitting power that could not be met simultaneously; therefore, an operational constraint would be imposed requiring that these activities be scheduled on an exclusive-OR basis. Both the medium- and high-accuracy range and range rate requirements could be met by the existing DSN S-band capability.

A natural constraint upon the time available for angle measurement activities in all three configurations would be the need to calibrate the system regularly. The system or "platform" would be calibrated by acquiring wideband VLBI data from selected extragalactic radio sources (ERS) to determine station clock rate and clock offset, station location, earth rotation rate, and polar motion. In addition, at less-frequent intervals, these same radio sources would be studied themselves to reevaluate their source characteristics to determine their continued usefulness in system calibration activities.

IV. Network Operations

A. General

The NAVNET stations would have to be provided with a one-way signal emanating from the spacecraft to make angle measurements on it. The spacecraft would have to be in the proper mode and have a reasonably stable oscillator. A wideband RF signal containing several discrete frequencies would be propagated and would be suitable for taking either DOR or Δ VLBI data at the stations. Several of the downlink frequencies would be used in resolving the ambiguity problem to produce the direct angle measurement, while one of the frequencies would be utilized in producing a concurrent angle-rate measurement.

B. Configuration 1

All Configuration 1 station operations are summarized in Table 2. There would be two possible ways of using the stations operationally. The preferred arrangement producing the most useful data from a processing viewpoint would be to schedule all three terminals to acquire either VLBI angle measurement or calibration data concurrently. An alternative arrangement would be to schedule two stations to provide east-west baseline data followed by the most westerly of the pair scheduled with the third station to provide north-south baseline data. Passes not exceeding 30 minutes in duration for each of the two- or three-station arrangements would suffice to meet the medium-accuracy and some lower high-accuracy angle measurements by acquiring DOR-type data. The highest high-accuracy angle measurement requirements would be obtained by acquiring Δ VLBI data during passes not exceeding 60 minutes in duration.

No pre- or postpass ground equipment calibration would be necessary for any of the station VLBI activities.

Range and range-rate data would be needed to support the data acquired during each angle measurement pass and would be provided primarily by the Goldstone anchor station. For the first arrangement, ranging data would be taken either before or after the three-station angle measurement pass period, which would result in the acquisition of less than optimal, low-angle doppler data. The "best" range rate data would be acquired in the second arrangement, between the end of the two-station east-west baseline angle measurement pass and the beginning of the two-station north-south baseline pass. The spacecraft would be at an optimal high angle, approaching the Goldstone meridian crossing, but still not yet in the best position for the north-south baseline pass to begin.

A typical ranging pass would require round-trip light time (RTLT) plus 45 minutes to complete. However, Saturn and

Neptune RTLTs could cause difficulties. Two remedies would be available. Firstly, backup stations at any of the complexes could be used. Secondly, a station could start a ranging signal towards the distant spacecraft, go to another activity, and then come back to the original spacecraft in time to receive the return of the ranging signal. Alternatively, a second station in common view could receive the returning signal. This second method would provide ranging values that are well within the limit of accuracy required in the future, based upon present station timing limitations.

C. Configurations 2 and 3

Station operations for Configurations 2 and 3 are summarized in Table 3. Each complex in Configuration 2 would have a station with existing 1980-era capabilities for the acquisition of angle/angle rate, platform parameters, and ERS calibration data. In Configuration 3, these stations would be additionally provided with X-band ranging and two-way doppler capability to increase the accuracy of these measurements and to provide backup to the prime station at Goldstone.

In both configurations, the Hawaiian terminal would be perceived as a backup for either Goldstone or Canberra. In Configuration 2, it would have an S/X-band listen-only capability as in Configuration 1, but in Configuration 3 it would be provided with the same capabilities as a NAVNET station at a DSN Complex.

In both configurations, angle measurements, platform and ERS calibration would be made by scheduling stations in east-west and north-south pairs because of DSN geographical constraints. The Goldstone NAVNET station would be regarded as prime for ranging and range-rate data acquisition. The range/range-rate schedule for the Goldstone anchor station would be organized on the same basis as for the second tracking arrangement of Configuration 1. The problems associated with very long RTLTs would also be mitigated by using the solutions previously described.

It should be noted that in all three configurations doppler data would continue to be available from the telemetry data acquisition passes made by other DSN stations and would be regarded as "bonus" data.

D. Correlator

The correlator would be remotely operated by NOCC staff. It would be loaded with the tracking schedule to enable an incoming signal to be identified. Typically, the sample signal would arrive on a wide-band data link and the ancillary data, for example antenna pointing angles, would be input from a high-speed line. Configuration 1 stations would provide real-time signals to the correlator, whereas Configuration 2 and 3

stations would record the navigation signal, buffer it, and transmit to the correlator in nonreal time. However, at intervals during each pass, a second or two of near-real time signal would be transmitted from each station via the high-speed data line to be integrated by the correlator to establish the presence or absence of "fringe" data. The hardware correlator design is tolerant of short-term signal interruptions caused by communications line "bumps," for example, and should not therefore be a significant source of pass rescheduling or signal replay. RTM alarms would alert NOCC staff to system problems. Should a data loss be observed at the correlator output, it would be a reasonable practice for the Operations Chief to abandon the remainder of any angle measurement pass, which would be characteristically of short duration, and use the time to assist in returning the system to an operable condition.

V. Network Loading Requirements

The Network loading requirement that was used to estimate the NAVNET station utilization was an assumed one and is shown in Table 4. Only deep-space missions were included in it. A total of seven active spacecraft were distributed such that five would be in a cruise mode throughout the strawman year under consideration, one would be in transition from a cruise mode to an extended planetary flyby mode, and a seventh would be in a planetary orbiter mode for six months of the year. This arrangement created a mix of medium- and high-accuracy angle measurement workload for the conceptual NAVNET.

It was determined that the medium-accuracy requirement for any of the assumed spacecraft would be satisfied by three passes per week, for both angle measurements and for ranging. An angle measurement pass under these conditions would take about 30 minutes to complete, assuming that the VLBI technique would be operational. The time needed for the associated ranging pass would be about RTLt plus 45 minutes. A flyby spacecraft near planetary encounter would require angle measurements to be made at the lower high-accuracy level. Daily angle and ranging passes of 30 minutes and RTLt plus 45 minutes duration, respectively, would suffice. A spacecraft in a planetary orbit mode would require angle measurements to be made at the higher high-accuracy level for which daily angle and ranging passes of 60 minutes and RTLt plus 45 minutes duration respectively would be necessary.

For the NAVNET to remain operationally available, it would be necessary to make regular calibrations of the system. The required calibration workload is included in Table 4 and would depend upon the level of accuracy required in making angle measurements on scheduled spacecraft. Whenever a high-accuracy measurement might have to be made, one

4-hour platform calibration pass per day per station pair would be needed or per station triplet if Configuration 1 were to be used. However, if long periods occurred when all the active spacecraft were in a cruise mode, for example, the resulting overall medium accuracy workload would require just one 4-hour platform calibration pass per station pair or trio per week. ERS characteristics calibrations would have to be made by the NAVNET at approximately 90-day intervals for all those sources that might be used during angle measurement or platform calibration activities. This task could not be done exclusively by a station pair, or trio, during the one- or two-day period needed. It would be scheduled at a time when the angle measurement workload could be minimized with Project concurrence.

VI. Station Workload

The most significant component in the utilization of a NAVNET station proved to be the communications workload. The simple calculations for a station angle measurement workload based upon the assumed mission set are shown in Fig. 1.

It was assumed that five spacecraft were in cruise mode, each one requiring three 30-minute (1/2 hour) passes per week for 52 weeks of the year, resulting in a total of 390 station hours. The flyby and planetary orbiter spacecraft each need the sum of two similar calculations to allow for the medium- and high-accuracy components of their flight profile. These show that the flyby would require 98 station hours and the planetary orbiter 221.

The platform calibration workload on the station was calculated on a worst-case basis. It was assumed that the planetary orbiter and planetary flyby high-accuracy periods of 26 weeks and 10 weeks, respectively, would not overlap. So daily platform measurements would be needed for 36 weeks of the year, and weekly ones for the remaining 16 weeks. The simple calculation based on these needs gave a total of 1072 hours. The radio source characteristics calibrations were assumed to take 24 hours, uninterrupted by the need to make spacecraft angle measurements, four times a year. This activity required a total of 96 station hours.

The total station hours needed to make angle measurements on the seven spacecraft and to make the supporting system calibrations was 1877 for an annual load factor of $1877/8760 = 0.21$.

The development of the communications workload for each station is also shown in Fig. 1. The system designer had made a tradeoff between antenna aperture size and the bit acquisition rate to limit the latter to 1 Mbit/s. Signal would be acquired

for the duration of an angle measurement pass, but for only half the duration of a platform or source characteristics calibration pass, since it was assumed that the antenna would spend half of the time slewing between radio sources. It was also assumed that radio source characteristics data would be recorded and subsequently mailed to JPL for processing, thereby avoiding the need for communication link transmission time.

In Configuration 1, the 1 Mbit/s communication link would be required for a period equal to the sum of the station angle tracking and platform calibration periods since all signal acquired would have to be transmitted to JPL in real time. This annual link time would be 1781 hours. In Configurations 2 and 3 it was assumed that the acquired signal for both angle measurement and platform calibration would be recorded at the rate of 1 Mbit/s and played back at 230 kbit/s for nonreal time transmission to JPL. Then the annual 230-kbit/s link time would be the sum of the station angle measurement hours plus one half of the platform calibration hours, all extended by the recording rate divided by the playback rate. This would require a total of 5400 hours, an annual load factor of 0.62.

VII. Remarks

The operational philosophy developed in the preceding narrative formed the basis for the M&O Life Cycle Cost development. These costs were defined in two principle categories, communications and personnel. Of the two, communications costs significantly exceeded the personnel costs in all three of the configurations that were studied. However, the communications costs proved to be the softest ones in the whole study for two reasons. Firstly, it turned out to be very difficult to obtain dependable costs in 1980 dollars for a hypothetical use of international satellite data links five years downstream. Secondly, the assumption that international satellite data link costs will remain high in comparison to similar domestic services, will act as a strong driver for advances in communications techniques aimed at dispensing with the need for the continuous full-time connection as is presently indicated.

Other important factors also emerged from the study and are summarized below.

- (1) In Configuration 1, the terminals would be operated in an unattended mode from JPL and the system would be subjected to the relative operational inflexibility of a signal having to be returned to JPL in real time. In addition, the Operations organization has had no real experience with remote operations so there would be much to learn about them.

- (2) In all the configurations studied, the station operating technique was invariant since the angle measurements and the system calibrations all depended on the VLBI principle. This parsimony of operating technique would offer significant opportunities to narrow down operator skill requirements thus reducing training costs, and for increased productivity because operating errors should be minimized and the range of operating procedures would be reduced.
- (3) All configurations required redundant hydrogen masers based upon existing and projected state of the art. This is because a hydrogen maser takes weeks, even months, to recover from a failure, and so would leave the system useless without a backup. The operational problems associated with these devices have yet to be solved.
- (4) The role of the NOCC would need to be upgraded to one of system control and monitoring from the present

one of station direction and monitoring. VLBI activity would introduce a data type whereby data would be produced at an NOCC-located correlator from signals acquired at, and transmitted to it, from at least two geographically separated stations. Therefore, recovery from system failure would have to begin at the NOCC where the data would be generated. Further system control functions would be conferred on the NOCC if Configuration 1 were to be implemented because the remote operator controls would be colocated with it.

- (5) The study has shown that it would be necessary to provide different physical routings between each NAVNET station and the NOCC for the simplex extra-wide-band data link and the full duplex voice link. Failure to do so would foil the system level troubleshooting activity that would be necessary in the event of a data loss at the correlator in the NOCC.

References

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Table 1. Configuration description^a

Configuration 1	Configuration 2	Configuration 3
Planning configuration	Existing DSN stations	Existing DSN stations
Hawaii, Washington State, and	S-band up, S- and X-band down	S-band and X-band up (not simultaneously)
Florida Stations	Two-way doppler and ranging	S-band and X-band down (simultaneously)
25-m antenna	Wideband VLBI, Δ VLBI	Two-way ranging (conventional at S-band, wide-band at X-band)
S/X receive only	Hawaii ^b	Two-way doppler at S- and X-band
Controlled and operated remotely	S/X Receive Only	Wideband VLBI, Δ VLBI
Maintained locally		Hawaii ^b
Goldstone anchor station		Two-way S/X-band doppler/range
Standard existing capability		

^aThe following features are common to all entries in the table:

X-band, for highest accuracy

S-band, for low, medium accuracy and system calibration

Calibration: wideband VLBI

Signal processing and correlation at JPL

^bBackup for North-South Baseline.

Table 2. Configuration 1 station operations^a

Arrangement No.	Terminal and station usage	Medium-accuracy activity (data type)	High-accuracy activity (data type)	External calibration activity (data type)
1	Florida/Washington State/Hawaii	Angle/angle rate (differenced one-way range)	Angle/angle rate (quasar-spacecraft differenced VLBI)	Platform calibration (wideband VLBI) radio source calibration (wideband VLBI)
	Goldstone ^b	Range/range rate (S-band ranging/doppler)	Range/range rate (S-band ranging/doppler)	N/A ^c
2	Florida/Washington State Washington State/Hawaii	Angle/angle rate (differenced one-way range)	Angle/angle rate (quasar-spacecraft differenced VLBI)	Platform calibration (wideband VLBI) radio source calibration (wideband VLBI)
	Goldstone ^b			N/A

^aTracking-arrangements, -accuracy, -calibration; data types and terminal usage.

^bRanging is not performed concurrently with angle tracking.

^cN/A = not applicable.

Table 3. Configurations 2 and 3 station operations^a

Station usage ^b	Medium-accuracy activity (data type)	High-accuracy activity (data type)	External calibration activity (data type)
Madrid/Goldstone	Angle/angle rate (differenced one-way range)	Angle/angle rate (quasar-spacecraft differenced VLBI)	Platform calibration (wideband VLBI) Radio source calibration (wideband VLBI)
Goldstone/Canberra			
Goldstone ^c (Config 2)	Range/range rate (S-band ranging/ doppler)	Range/range rate (S-band ranging/ doppler)	N/A ^d
Goldstone ^c (Config 3)	Range/range rate (S- or X-band ranging/doppler)	Range/range rate (S- or X-band Ranging/doppler)	N/A

^aTracking-arrangements (only one arrangement is possible due to DSN geography)
-accuracy, -calibration; data types and terminal usage.

^bHawaiian station is standby for Goldstone or Canberra.

^cRanging is not performed concurrently with angle tracking.

^dN/A = not applicable.

Table 4. Network loading requirements

Assumed tracking workload										
Spacecraft (mode)	Medium-accuracy workload					High-accuracy workload				
	Weeks/ year	Angle data		Range data		Weeks/ year	Angle data		Range data	
		Passes/ week	Duration, min.	Passes/ week	Duration, min.		Passes/ week	Duration, min.	Passes/ week	Duration, min.
5 (cruise)	52	3	30	3	RTLT + 45	—	—	—	—	—
1 (flyby)	42	3	30	3	RTLT + 45	10	7	30	7	RTLT + 45
1 (orbiter)	26	3	30	3	RTLT + 45	26	7	60	7	RTLT + 45
Required calibration workload										
1. Platform calibration: one 4-h pass/week/station pair if high accuracy not needed one 4-h pass/day/station pair if high accuracy needed										
2. Source calibration: one 1-day pass/quarter/station pair with minimized tracking load										

ANGLE-TRACKING WORKLOAD	
5 (CRUISE) X 3 X 1/2 X 52	= 390
[1 (FLYBY) X 3 X 1/2 X 42] + [1 X 7 X 1/2 X 10]	= 98
[1 (ORBITER) X 3 X 1/2 X 26] + [1 X 7 X 1 X 26]	= 221
PLATFORM CALIBRATION WORKLOAD	709 h
(7 X 4 X 36) + (1 X 4 X 16)	= 1072 h
SOURCE CALIBRATION WORKLOAD	
ASSUME THAT THERE IS NO INTERFERENCE WITH ANGLE TRACKING AND PLATFORM CALIBRATIONS	
24 X 4	= 96 h
	<u>1877 h TOTAL</u>
COMMUNICATIONS WORKLOAD	
CONFIGURATION 1	
ASSUME ANGLE IS ACQUIRED AT 1 Mbit/s AND RETURNED IN REAL TIME	
ASSUME PLATFORM CALIBRATION DATA IS ACQUIRED AT 1 Mbit/s FOR HALF THE VIEW PERIOD AND IS RETURNED IN REAL TIME	
ASSUME RADIO SOURCE DATA IS RECORDED AND MAILED FOR DATA PROCESSING	
THEN 1 Mbit/s COMM TIME = 709 + 1072 = <u>1781 h TOTAL</u>	
CONFIGURATIONS 2 AND 3	
ASSUME ANGLE DATA IS ACQUIRED AT 1 Mbit/s RECORDED AND PLAYED BACK IN NRT AT 230 kbit/s	
ASSUME PLATFORM CALIBRATION DATA IS ACQUIRED AT 1 Mbit/s FOR HALF THE VIEW PERIOD, RECORDED AND PLAYED BACK IN NRT AT 230 kbit/s	
ASSUME RADIO SOURCE CALIBRATION DATA IS RECORDED AND MAILED FOR DATA PROCESSING	
THEN 230 kbit/s COMM TIME = (709 + 1072 X 1/2) X $\frac{1000}{230}$ = 5400 h TOTAL	

Fig. 1. Angle-tracking station workload